GUIDANCE DOCUMENT

DEVELOPMENT OF SITE-SPECIFIC IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS USING THE SOIL-WATER PARTITION EQUATION

December 2008

Revised

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I. Introduction

This guidance describes the use of the Soil-Water Partition Equation to develop site-specific impact to ground water (IGW) soil remediation standards.

A modified version of the USEPA Soil Screening Level (SSL) Soil-Water Partition Equation (USEPA, 1996b, Equation 24) may be used to calculate site-specific IGW soil remediation standards. The Department expanded Equation 24 to separate the target leachate concentration discussed in the USEPA SSL guidance document into its component parts. The target leachate concentration is the product of the health-based ground water criterion (C_{gw}), and the dilution-attenuation factor (DAF). This modification allows the Department's health-based Ground Water Quality Criterion to be directly entered as an input parameter**.**

The equations for calculating site-specific IGW soil remediation standards are provided in Equations 1a and 1b below. The Soil-Water Partition Equation back-calculates a concentration in soil from an acceptable ground water concentration.

The Department has provided a table of IGW soil screening levels (Table 1) considering the health based Class II-A ground water quality criteria using default site conditions and assumptions. The screening levels provided in Table 1 are appropriate for use at sites where no site-specific data are available.

For Class I and III ground water, ground water quality criteria must be developed by the Department on a site-specific basis. IGW soil remediation standards are then back calculated from ground water criteria using the Soil-Water Partition Equation.

Although this methodology can be used for all contaminants it is <u>not</u> recommended for metals unless a site specific Kd has been developed using the SPLP procedure (See the SPLP Guidance document). The speciation of a metal greatly influences its adsorptive capacity, or Kd, and therefore its mobility. Because the soil-water equation methodology does not take speciation into account, the methodology may result in a more conservative standard than is appropriate for the site.

The Department has provided a multi-faceted spreadsheet that will enable the person conducting the remediation to quickly and easily generate site-specific soil remediation standards that will be protective of ground water.

II. Soil-Water Partition Equation Assumptions

The USEPA SSL Soil-Water Partition Equation assumes that contaminants in soil exist in equilibrium between the sorbed phase (on soil solids), aqueous phase (in soil moisture) and vapor phase (in the soil airspace). The equation calculates the total amount of the contaminant that may be left behind in the soil so that the aqueous phase concentration of a contaminant will not exceed a specified criterion (the health-based Ground Water Quality Criteria).

Because soil water will be diluted once it enters the ground water, a dilution-attenuation factor (DAF) is included in the equation to account for this process. However, the model does not account for dilution of the contaminant due to transport through the unsaturated soil zone or chemical degradation. The model assumes that the soil contamination is immediately adjacent to the water table; and that the health-based Ground Water Quality Criteria must be achieved directly under the area of concern, immediately after remediation.

III. Equations for calculating the soil remediation criteria

For organic contaminants:

$$IGWSRS = C_{gw}\left\{(K_{oc}\, f_{oc}) + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF \qquad \textbf{Equation 1a}$$

For inorganic contaminants:

$$IGWSRS = C_{gw}\left\{(K_d) + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF \qquad \textbf{Equation 1b}$$

$IGWSRS$ = Impact-to-ground water soil remediation standard (mg/kg)
C_{gw} = Ground Water Quality Criterion (mg/L)
f_{oc} = organic carbon content of soil (kg/kg)
K_d = soil-water partition coefficient (L/kg)
θ_w = water-filled soil porosity (L_{water}/L_{soil})
θ_a = air-filled soil porosity (L_{air}/L_{soil})
H' = Henry's law constant (dimensionless)
ρ_b = dry soil bulk density (kg/L)
DAF = dilution-attenuation factor

IV. Practical Quantitation Levels (PQLs)

Compare the derived standard to the soil practical quantitation level (PQL) for each contaminant listed in the Remediation Standards, N.J.A.C. 7:26D Tables 1A and 1B. The IGW soil remediation standards will be the higher of the health-based criterion or the PQL.

V. Soil Saturation Limit (Csat)

The Department requires, pursuant to the Technical Requirements for Site Remediation N.J.A.C. 7:26E-6.1(d), that non-aqueous phase liquid (NAPL), or free and residual product, must be treated or removed when ever practicable. The concentration at which non-aqueous phase liquid (NAPL) begins to form is referred to, in the USEPA SSL guidance document, as the Soil Saturation Limit.

The USEPA SSL guidance document contains an equation for calculating the Soil Saturation Concentration (USEPA 1996b):

Soil Saturation Concentration Equation:

$$C_{sat} = \frac{S}{\rho_b}(K_{oc} f_{oc} \rho_b + \theta_w + H'\theta_a) \qquad \textbf{Equation 2}$$

Where C_{sat} is the soil saturation concentration (mg/kg), S is the contaminant's water solubility (mg/L), and the remaining parameters are as defined earlier. Values for the input parameters are the same as those for Equations 1a and 1b above. Soil saturation concentrations are listed in the Chemical Properties Table.

http://www.nj.gov/dep/srp/guidance/rs/chemproperties.pdf

Di-n-octyl phthalate is limited by its soil saturation concentration as indicated in Table 1 below.

VI. Developing a site-specific impact to ground water soil remediation standard

A spreadsheet is available from the Department that will calculate site-specific impact to ground water soil remediation standards. The spreadsheet has a built in database that includes the necessary chemical properties and ground water criteria. The spreadsheet will also factor in Csat values, soil PQLs and Arsenic statewide background value when developing a site-specific soil remediation standard.

http://www.nj.gov/dep/srp/guidance/rs/partition_equation.xls

1. For sites with no site-specific information

A site-specific soil remediation standard may be calculated using Equation 1a for organic contaminants or Equation 1b for inorganic contaminants with the following default parameters:

Soil-Water Partition Equation Default Input Parameters	
Parameter	**DEP Default Value**
Health-based ground water criteria, C_{gw}	chemical specific
Fraction organic carbon, f_{oc}	0.002
Soil-water partition coefficient, K_d *or* K_{oc}	chemical specific
Water content, θ_w	0.23
Air content, θ_a (L_{air}/L_{soil})	0.18
Henry's law constant at 25°C, *H'* (dimensionless)	chemical specific
Dry soil bulk density, ρ_b (kg/L)	1.5
Dilution attenuation factor, DAF	13

A table of Default Impact to Ground Water Soil Screening Levels is provided below (Table 1). These screening levels were calculated considering the health based Class II-A ground water quality criteria and soil water partition equation. They may be used at sites where no site specific information is available.

Table 1
Default Impact to Ground Water Soil Screening Levels for Contaminants (mg/kg)

Contaminant	CAS Number	Health based Ground Water Quality Criteria (µg/L)	Default Impact to GW Health Based Soil Screening Level (mg/kg)	Soil PQL (mg/kg)	Impact to GW Soil Screening Level (mg/kg)
Acenaphthene	83-32-9	400	74	0.2	74
Acenaphthylene	208-96-8	NA	NA	0.2	NA
Acetone (2-propanone)	67-64-1	6000	12	0.01	12
Acetophenone	98-86-2	700	2	0.2	2
Acrolein	107-02-8	4	0.008	0.5	0.5†
Acrylonitrile	107-13-1	0.06	0.0001	0.5	0.5†
Aldrin	309-00-2	0.002	0.1	0.002	0.1
Aluminum	7429-90-5	200	3900	20	3900
Anthracene	120-12-7	2000	1500	0.2	1500
Antimony	7440-36-0	6	4	6	6†
Arsenic	7440-38-2	0.02	0.006	1	19*
Atrazine	1912-24-9	3	0.03	0.2	0.2†
Barium	7440-39-3	6000	1300	20	1300
Benzaldehyde	100-52-7	NA	NA	0.2	NA
Benzene	71-43-2	0.2	0.0008	0.005	0.005†
Benzidine	92-87-5	0.0002	0.0000006	0.7	0.7†
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	0.05	0.5	0.2	0.5
Benzo(a)pyrene	50-32-8	0.005	0.1	0.2	0.2†
Benzo(b)fluoranthene (3,4-benzofluoranthene)	205-99-2	0.05	2	0.2	2
Benzo(ghi)perylene	191-24-2	NA	NA	0.2	NA
Benzo(k)fluoranthene	207-08-9	0.5	16	0.2	16

Table 1 Default Impact to Ground Water Soil Screening Levels for Contaminants (mg/kg)					
Contaminant	**CAS Number**	**Health based Ground Water Quality Criteria (µg/L)**	**Default Impact to GW Health Based Soil Screening Level (mg/kg)**	**Soil PQL (mg/kg)**	**Impact to GW Soil Screening Level (mg/kg)**
Beryllium	7440-41-7	1	0.5	0.5	0.5
1,1'-Biphenyl	92-52-4	400	90	0.2	90
Bis(2-chloroethyl)ether	111-44-4	0.03	0.00007	0.2	0.2†
Bis(2-chloroisopropyl)ether	108-60-1	300	3	0.2	3
Bis(2-ethylhexyl)phthalate	117-81-7	2	790	0.2	790
Bromodichloromethane (Dichlorobromomethane)	75-27-4	0.6	0.002	0.005	0.005†
Bromoform	75-25-2	4	0.02	0.005	0.02
Bromomethane (Methyl bromide)	74-83-9	10	0.03	0.005	0.03
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3	300	0.6	0.01	0.6
Butyl benzyl phthalate	85-68-7	100	150	0.2	150
Cadmium	7440-43-9	4	1	0.5	1
Caprolactam	105-60-2	3500	8	0.2	8
Carbazole	86-74-8	NA	NA	0.2	NA
Carbon disulfide	75-15-0	700	4	0.5	4
Carbon tetrachloride	56-23-5	0.4	0.003	0.005	0.005†
Chlordane (alpha and gamma)	57-74-9	0.01	0.03	0.002	0.03
Chlorobenzene	108-90-7	50	0.4	0.005	0.4
Chloroethane (Ethyl chloride)	75-00-3	NA	NA	0.005	NA
Chloroform	67-66-3	70	0.2	0.005	0.2
Chloromethane (Methyl chloride)	74-87-3	NA	NA	0.005	NA
2-Chlorophenol (o-Chlorophenol)	95-57-8	40	0.5	0.2	0.5
Chrysene	218-01-9	5	52	0.2	52
Cobalt	7440-48-4	100	59	5	59
Copper	7440-50-8	1300	7300	3	7300
Cyanide	57-12-5	100	13	3	13
4,4’-DDD	72-54-8	0.1	3	0.003	3
4,4’-DDE	72-55-9	0.1	12	0.003	12
4,4’-DDT	50-29-3	0.1	7	0.003	7
Dibenz(a,h)anthracene	53-70-3	0.005	0.5	0.2	0.5
Dibromochloromethane (Chlorodibromomethane)	124-48-1	0.4	0.001	0.005	0.005†
1,2-Dibromo-3-chloropropane	96-12-8	0.02	0.00008	0.005	0.005†
1,2-Dibromoethane (ethylene dibromide)	106-93-4	0.0004	0.000001	0.005	0.005†
1,2-Dichlorobenzene (o-Dichlorobenzene)	95-50-1	600	11	0.005	11
1,3-Dichlorobenzene (m-Dichlorobenzene)	541-73-1	600	12	0.005	12
1,4-Dichlorobenzene (p-Dichlorobenzene)	106-46-7	75	1	0.005	1
3,3'-Dichlorobenzidine	91-94-1	0.08	0.002	0.2	0.2†
Dichlorodifluoromethane	75-71-8	1000	25	0.005	25
1,1-Dichloroethane	75-34-3	50	0.2	0.005	0.2
1,2-Dichloroethane	107-06-2	0.3	0.0008	0.005	0.005†
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	1	0.005	0.005	0.005
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	70	0.2	0.005	0.2
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	100	0.4	0.005	0.4
2,4-Dichlorophenol	120-83-2	20	0.1	0.2	0.2†
1,2-Dichloropropane	78-87-5	0.5	0.002	0.005	0.005†
1,3-Dichloropropene (cis and trans) (summed)	542-75-6	0.4	0.002	0.005	0.005†
Dieldrin	60-57-1	0.002	0.001	0.003	0.003†

Table 1 Default Impact to Ground Water Soil Screening Levels for Contaminants (mg/kg)					
Contaminant	**CAS Number**	**Health based Ground Water Quality Criteria (µg/L)**	**Default Impact to GW Health Based Soil Screening Level (mg/kg)**	**Soil PQL (mg/kg)**	**Impact to GW Soil Screening Level (mg/kg)**
Diethyl phthalate	84-66-2	6000	57	0.2	57
2,4-Dimethylphenol	105-67-9	100	0.7	0.2	0.7
Di-n-butyl phthalate	84-74-2	700	620	0.2	620
4,6-Dinitro-2-methylphenol (4,6-Dinitro-o-cresol)	534-52-1	0.7	0.004	0.3	0.3†
2,4-Dinitrophenol	51-28-5	10	0.02	0.3	0.3†
2,4-Dinitrotoluene	121-14-2	NA	NA	0.2	NA
2,6-Dinitrotoluene	606-20-2	NA	NA	0.2	NA
2,4-Dinitrotoluene/2,6-Dinitrotoluene (mixture)	121-14-2/606-20-2	0.05	0.0002	0.2	0.2†
Di-n-octyl phthalate	117-84-0	100	220000	0.2	3300**
1,2-Diphenylhydrazine	122-66-7	0.04	0.0008	0.7	0.7†
Endosulfan I and Endosulfan II (alpha and beta)	115-29-7	40	2	0.003	2
Endosulfan sulfate	1031-07-8	40	1	0.003	1
Endrin	72-20-8	2	0.6	0.003	0.6
Ethyl benzene	100-41-4	700	8	0.005	8
Fluoranthene	206-44-0	300	840	0.2	840
Fluorene	86-73-7	300	110	0.2	110
Alpha-HCH (alpha-BHC)	319-84-6	0.006	0.0002	0.002	0.002†
Beta-HCH (beta-BHC)	319-85-7	0.02	0.0007	0.002	0.002†
Heptachlor	76-44-8	0.008	0.3	0.002	0.3
Heptachlor epoxide	1024-57-3	0.004	0.009	0.002	0.009
Hexachlorobenzene	118-74-1	0.02	0.03	0.2	0.2†
Hexachloro-1,3-butadiene	87-68-3	0.4	0.6	0.2	0.6
Hexachlorocyclopentadiene	77-47-4	40	210	0.2	210
Hexachloroethane	67-72-1	2	0.1	0.2	0.2†
Indeno(1,2,3-cd)pyrene	193-39-5	0.05	5	0.2	5
Isophorone	78-59-1	40	0.1	0.2	0.2†
Lead	7439-92-1	5	59	1	59
Lindane (gamma-HCH) (gamma-BHC)	58-89-9	0.03	0.0009	0.002	0.002†
Manganese	7439-96-5	50	42	2	42
Mercury	7439-97-6	2	0.009	0.1	0.1†
Methoxychlor	72-43-5	40	100	0.02	100
Methyl acetate	79-20-9	7000	14	0.005	14
Methylene chloride (Dichloromethane)	75-09-2	3	0.007	0.005	0.007
2-Methylnaphthalene	91-57-6	30	5	0.17	5
2-Methylphenol (o-cresol)	95-48-7	NA	NA	0.2	NA
4-Methylphenol (p-cresol)	106-44-5	NA	NA	0.2	NA
Methyl tert-butyl ether (MTBE)	1634-04-4	70	0.2	0.005	0.2
Naphthalene	91-20-3	300	16	0.2	16
Nickel (Soluble salts)	7440-02-0	100	31	4	31
2-Nitroaniline	88-74-4	NA	NA	0.3	NA
Nitrobenzene	98-95-3	4	0.01	0.2	0.2†
N-Nitrosodimethylamine	62-75-9	0.0007	0.000001	0.7	0.7†
N-Nitrosodi-n-propylamine	621-64-7	0.005	0.00001	0.2	0.2†
N-Nitrosodiphenylamine	86-30-6	7	0.2	0.2	0.2
Pentachlorophenol	87-86-5	0.3	0.04	0.3	0.3†

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Phenanthrene	85-01-8	NA	NA	0.2	NA
Phenol	108-95-2	2000	5	0.2	5
Polychlorinated biphenyls (PCBs)	81336-36-3	0.02	0.2	0.03	0.2
Pyrene	129-00-0	200	550	0.2	550
Selenium	7782-49-2	40	7	4	7
Silver	7440-22-4	40	0.2	1	1†
Styrene	100-42-5	100	2	0.005	2
Tertiary butyl alcohol (TBA)	75-65-0	100	0.2	0.1	0.2
1,1,2,2-Tetrachloroethane	79-34-5	1	0.004	0.005	0.005†
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	0.4	0.003	0.005	0.005†
Thallium	7440-28-0	0.5	0.3	3	3†
Toluene	108-88-3	600	4	0.005	4
Toxaphene	8001-35-2	0.03	0.2	0.2	0.2
1,2,4-Trichlorobenzene	120-82-1	9	0.4	0.005	0.4
1,1,1-Trichloroethane	71-55-6	30	0.2	0.005	0.2
1,1,2-Trichloroethane	79-00-5	3	0.01	0.005	0.01
Trichloroethene (TCE) (Trichloroethylene)	79-01-6	1	0.007	0.005	0.007
Trichlorofluoromethane	75-69-4	2000	22	0.005	22
2,4,5-Trichlorophenol	95-95-4	700	44	0.2	44
2,4,6-Trichlorophenol	88-06-2	1	0.03	0.2	0.2†
Vanadium	7440-62-2	NA	NA	5	NA
Vinyl chloride	75-01-4	0.08	0.0003	0.005	0.005†
Xylenes	1330-20-7	1000	12	0.005	12
Zinc	7440-66-6	2000	600	6	600

NA = Standard not available   *Health based criterion defaults to background   **Health based criterion defaults to soil saturation limit
† standard set at PQL

2. For sites with site-specific information

A site-specific soil remediation standard may be calculated using site-specific information. Certain input parameters in Equations 1a and 1b lend themselves fairly easily to site-specific modification. The use of site data to modify default input parameters in the soil-water partition equation may generate a higher remediation standard that is still protective and appropriate for a given site. Some input parameters will have a greater effect on raising a criterion than others. In particular, higher values for soil organic carbon content, higher ground water flow rates, and for metals and ionizable phenols, higher soil pH will have the greatest effect on increasing the remediation standard.

Calculate a site-specific IGW soil remediation standard using site-specific input parameters in Equation 1a or 1b as follows:

a. Site-specific values may be derived for 4 different input parameters using the procedures provided below. Use the default values provided above for the input parameters when no site-specific values are available.

b. For Class II ground water, use the health-based ground water quality criteria, N.J.A.C. 7:9C.

c. Use the chemical properties that are provided in the Chemical Properties Table. http://www.nj.gov/dep/srp/guidance/rs/chemproperties.pdf

d. The site-specific IGW soil remediation standard will be based on the calculated health-based criterion or the soil practical quantitation levels PQL which ever is higher.

e. For Class I or III ground water, the Department will develop site-specific health-based ground water quality criterion appropriate for the ground water classification on which a site-specific IGW soil remediation standard can be based.

VII. Derivation of Site-Specific Parameters

The following parameters may be based on site-specific information and used in Equation 1a or 1b to develop a site-specific IGW soil remediation standard.

1. Fraction organic carbon - foc

Soil organic carbon content is used with a contaminant's K_{oc} value to determine the extent that the contaminant will be adsorbed to the soil. In general, the soil remediation standard is linearly related to the organic carbon content. For example, a doubling of the organic carbon content of the soil will double the calculated remediation standard. The Lloyd Kahn method is available to determine organic carbon content of soil (USEPA, 1988). Determine a site-specific fraction organic carbon as follows:

a. Collect a minimum of 3 soil samples from locations at the site that are representative of the area of concern including soil type and contaminant depth. Samples should not be collected from areas with high levels of organic contamination (greater than 1,000 ppm) because high levels of organic contaminants will contribute to an artificially high carbon content.

b. Analyze the samples for soil organic carbon content using the Lloyd Kahn Method.

c. Use the average soil organic carbon content as f_{oc} in the Equation 1a or 1b to develop a site-specific criterion. If the f_{oc} values vary by more than an order of magnitude, they may not be averaged to develop a site-specific criterion. In this case, the lowest f_{oc} value must be used to develop a site-specific criterion.

Additional soil samples should be collected when soil types vary across the area of concern or when the area of concern is larger than 100 feet in size. (See DAF Guidance Document).

2. Soil-water partition coefficient - K_d

a. Use the SPLP Guidance Document to derive a site-specific soil-water partition coefficient, K_d .

b. Substitute the derived K_d value into Equation 1a or Equation 1b.

3. Dilution attenuation factor - DAF

a. Develop a site-specific dilution attenuation factor following the DAF guidance document.

b. Substitute the site-specific DAF into Equation 1a or Equation 1b.

4. Ionizable phenol Koc values for soil pH

For ionizable phenols, the adsorption constant (K_{oc}) is dependant on soil pH (USEPA, 1996b). A site-specific soil remediation standard may be developed for ionizable phenols for which pH-dependant K_{oc} values (USEPA, 1996a). Determine a site-specific K_{oc} as follows:

a. Collect a minimum of 3 soil samples from locations at the site that are representative of the area of concern including soil type and contaminant depth.

b. Measure the soil pH in each sample using standard methods.

c. Use the soil pH value for each sample to select a soil organic carbon-water partition coefficient (K_{oc}) for the contaminant from Table 2 below. If the measured soil pH is less than 4.9, use the K_{oc} for pH 4.9. If the measured pH is higher than 8.0, use the K_{oc} value for pH 8.0.

d. Use the resulting K_{oc} value in Equation 1a or 1b to calculate the site-specific IGW soil remediation standard for each sample. If the calculated standards vary by less than an order of magnitude, they may be averaged to determine the site-specific IGW soil remediation standard. If calculated standards vary by more than an order of magnitude, the lowest calculated standard must be selected as the site-specific IGW soil remediation standard.

Additional soil samples should be collected where soil types vary across the area of concern is larger than 100 feet. (See the DAF Guidance Document)

Table 2
Koc Values (L/kg) for Ionizing Organics as a' Function of pH

pH	Benzoic Acid	2-Chloro-Phenol	2,4-Dichloro-phenol	2,4- Dinitro-phenol	Pentachloro-phenol	2,3,4,5-Tetrachloro-Phenol	2,3,4,6-Tetrachloro-phenol	2,4,5-Trichloro-Phenol	2,4,6 Trichloro-phenol
4.9	5.54E+00	3.98E+02	1.59E+02	2.94E-02	9.05E+03	1.73E+04	4.45E+03	2.37E+03	1.04E+03
5.0	4.64E+00	3.98E+02	1.59E+02	2.55E-02	7.96E+03	1.72E+04	4.15E+03	2.36E+03	1.03E+03
5.1	3.88E+00	3.98E+02	1.59E+02	2.23E-02	6.93E+03	1.70E+04	3.83E+03	2.36E+03	1.02E+03
5.2	3.25E+00	3.98E+02	1.59E+02	1.98E-02	5.97E+03	1.67E+04	3.49E+03	2.35E+03	1.01 E+03
5.3	2.72E+00	3.98E+02	1.59E+02	1.78E-02	5.10E+03	1.65E+04	3.14E+03	2.34E+03	9.99E+02
5.4	2.29E+00	3.98E+02	1.58E+02	1.62E-02	4.32E+03	1.61 E+04	2.79E+03	2.33E+03	9.82E+02
5.5	1.94E+00	3.97E+02	1.58E+02	1.50E-02	3.65E+03	1.57E+04	2.45E+03	2.32E+03	9.62E+02
5.6	1.65E+00	3.97E+02	1.58E+02	1.40E-02	3.07E+03	1.52E+04	2.13E+03	2.31E+03	9.38E+02
5.7	1.42E+00	3.97E+02	1.58E+02	1.32E-02	2.58E+03	1.47E+04	1.83E+03	2.29E+03	9.10E+02
5.8	1.24E+00	3.97E+02	1.58E+02	1.25E-02	2.18E+03	1.40E+04	1.56E+03	2.27E+03	8.77E+02
5.9	1.09E+00	3.97E+02	1.57E+02	1.20E-02	1.84E+03	1.32E+04	1.32E+03	2.24E+03	8.39E+02
6.0	9.69E-01	3.96E+02	1.57E+02	1.16E-02	1.56E+03	1.24E+04	1.11 E+03	2.21 E+03	7.96E+02
6.1	8.75E-01	3.96E+02	1.57E+02	1.13E-02	1.33E+03	1.15E+04	9.27E+02	2.17E+03	7.48E+02
6.2.	7.99E-01	3.96E+02	1.56E+02	1.10E-02	1.15E+03	1.05E+04	7.75E+02	2.12E+03	6.97E+02
6.3	7.36E-01	3.95E+02	1.55E+02	1.08E-02	9.98E+02	9.51 E+03	6.47E+02	2.06E+03	6.44E+02
6.4	6.89E-01	3.94E+02	1,54E+02	1.06E-02	8.77E+02	8.48E+03	5.42E+02	1.99E+03	5.89E+02
6.5	6.51 E-01	3.93E+02	1.53E+02	1.05E-02	7.81 E+02	7.47E+03	4.55E+02	1.91 E+03	5.33E+02
6.6	6.20E-01	3.92E+02	1.52E+02	1.04E-02	7.03E+02	6.49E+03	3.84E+02	1.82E+03	4.80E+02
6.7	5.95E-01	3.90E+02	1.50E+02	1.03E-02	6.40E+02	5.58E+03	3.27E+02		4.29E+02
6.8	5.76E-01	3.88E+02	1.47E+02	1.02E-02	5.92E+02	4.74E+03	2.80E+02	1.60E+03	3.81 E+02
6.9	5.60E-01	3.86E+02	1.45E+02	1.02E-02	5.52E+02	3.99E+03	2.42E+02	1.47E+03	3.38E+02
7.0	5.47E-01	3.83E+02	1.41 E+02	1.02E-02	5.21 E+02	3.33E+03	2.13E+02	1.34E+03	3.00E+02
7.1	5.38E-01	3.79E+02	1.38E+02	1.02E-02	4.96E+02	2.76E+03	1.88E+02	1.21E+03	2.67E+02
7.2	5.32E-01	3.75E+02	1.33E+02	1.01 E-02	4.76E+02	2.28E+03	1.69E+02	1.07E+03	2.39E+02
7.3	5.25E-01	3.69E+02	1.28E+02	1.01E-02	4.61 E+02	1.87E+03	1.53E+02	9.43E+02	2.15E+02
7.4	5.19E-01	3.62E+02	1.21 E+02	1.01 E-02	4.47E+02	1.53E+03	1.41 E+02	8.19E+02	1.95E+02
7.5	5.16E-01	3.54E+02	1.14E+02	1.01 E-02	4.37E+02	1.25E+03	1.31 E+02	7.03E+02	1.78E+02
7.6	5.13E-01	3.44E+02	1.07E+02	1.01 E-02	4.29E+02	1.02E+03	1.23E+02	5.99E+02	1.64E+02
7.7	5.09E-01	3.33E+02	9.84E+01	1.00E-02	4.23E+02	8.31 E+02	1.17E+02	5.07E+02	1.53E+02
7.8	5.06E-01	3.19E+02	8.97E+01	1.00E-02	4.18E+02	6.79E+02	1.13E+02	4.26E+02	1.44E+02
7.9	5.06E-01	3.04E+02	8.07E+01	1.00E-02	4.14E+02	5.56E+02	1.08E+02	3.57E+02	1.37E+02
8.0	5.06E-01	2.86E+02	7.17E+01	1.00E-02	4.10E+02	4.58E+02	1.05E+02	2.98E+02	1.31 E+02

VIII. Submission Requirements

1. Depict all sample locations, depths and contaminant concentrations on a scaled map.

2. Site-specific impact to ground water soil remediation standards should be developed using soil-water partition equation spreadsheet.

3. Both a hard copy and an electronic copy of the spreadsheet must be submitted to the Department.

APPENDIX A

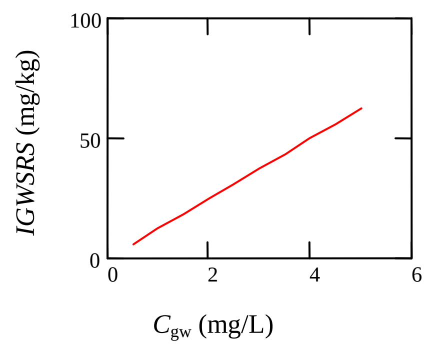
Sensitivity of the Soil-Water Partition Equation to Modification of Component Parameters

The Department conducted a sensitivity analysis of the USEPA partition equation to determine the effects of modifying different equation parameters on the development of soil remediation standard. For this analysis, one variable was modified at a time, while the other chemical and environmental parameter values were set at default New Jersey values. Soil properties were varied within their normal ranges (USEPA, 1996b). The analysis was conducted in two phases. First, the sensitivity of Equation 1 was evaluated with respect to the organic carbon content, K_{oc}, K_d, Henry's law constant, ground water standard, the dilution-attenuation factor (*DAF*), soil moisture, soil air content, and soil bulk density. Second, the sensitivity of the *DAF* calculations (Equations 2 and 3) to the various parameters incorporated was evaluated. The examples below are for specific contaminants, but the observed sensitivities are the same for all contaminants.

1. Sensitivity of the remediation standard (*IGWSRS*) to changes to the ground water standard (C_{gw}).
   Results shown for xylene

C_{gw} (mg/L)	*IGWSRS* (mg/kg)
0.5	6.2
1	12.5
1.5	18.7
2	24.9
2.5	31.2
3	37.4
3.5	43.6
4	49.8
4.5	56.1
5	62.3

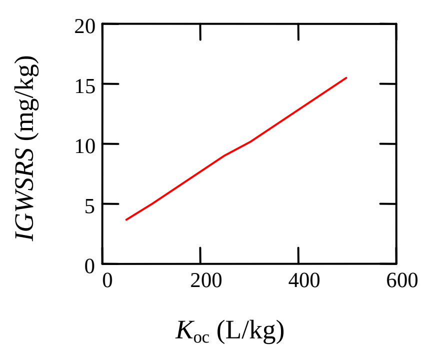
Sensitivity to groundwater criteria is linear



2. Sensitivity of remediation standard (*IGWSRS*) to changes to the (K_{oc}) soil organic carbon-water partition coefficient value.
   Results shown for xylene

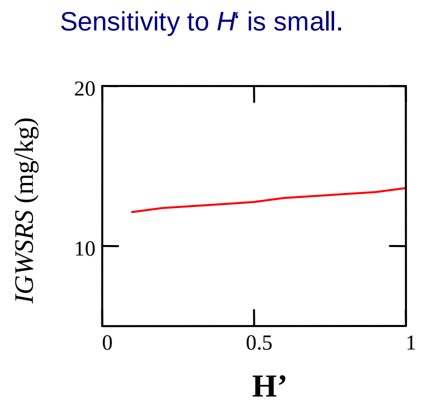
K_{oc} (L/kg)	*IGWSRS* (mg/kg)
50	3.7
100	5
150	6.3
200	7.6
250	8.9
300	10.2
350	11.5
400	12.8
450	14.1
500	15.4

Sensitivity to K_{oc} is linear.



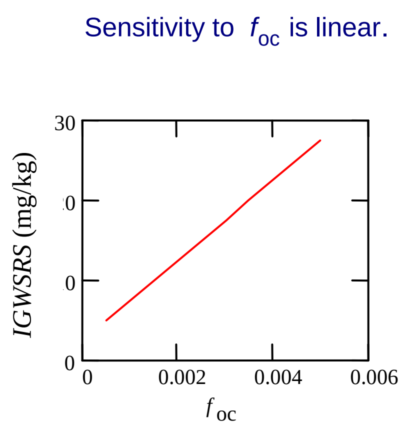
3. Sensitivity of remediation standard (*IGWSRS*) to the Henry's law constant (*H'*). Results shown for xylene

H'	*IGWSRS* (mg/kg)
0.1	12.2
0.2	12.3
0.3	12.5
0.4	12.6
0.5	12.8
0.6	13
0.7	13.1
0.8	13.3
0.9	13.4
1	13.6



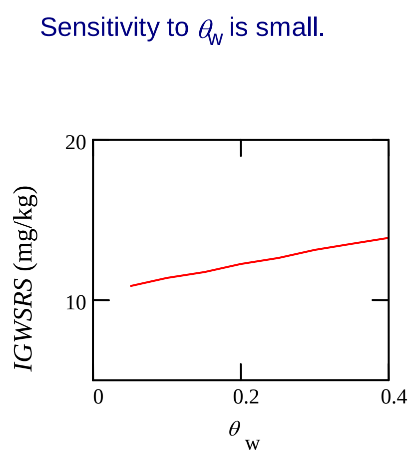
4. Sensitivity of remediation standard (*IGWSRS*) to fraction organic carbon (f_{oc}). Results shown for xylene.

f_{oc}	*IGWSRS* (mg/kg)
0.0005	4.9
0.001	7.4
0.0015	10
0.002	12.5
0.0025	15
0.003	17.5
0.0035	20
0.004	22.5
0.0045	25
0.005	27.5



5. Sensitivity of remediation standard (*IGWSRS*) to soil moisture (θ_w) Results shown for xylene.

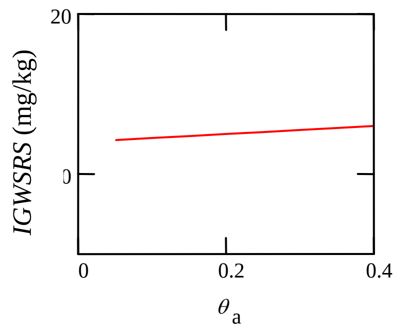
θ_w	*IGWSRS* (mg/kg)
0.05	10.9
0.1	11.3
0.15	11.8
0.2	12.2
0.25	12.6
0.3	13.1
0.35	13.5
0.4	13.9



6. Sensitivity of remediation standard (*IGWSRS*) to soil air content (θ_a). Results shown for xylene.

θ_a	*IGWSRS* (mg/kg)
0.05	12.1
0.1	12.3
0.15	12.4
0.2	12.5
0.25	12.6
0.3	12.7
0.35	12.9
0.4	13

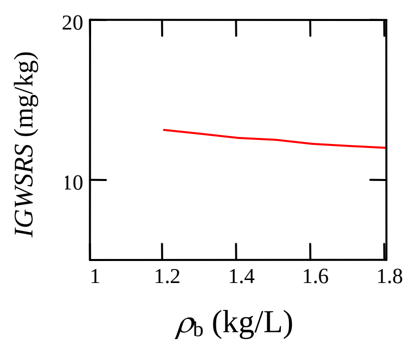
Sensitivity to θ_a is small



7. Sensitivity of remediation (*IGWSRS*) to soil bulk density (ρ_b)
Results shown for xylene.

ρ_b (kg/L)	*IGWSRS* (mg/kg)
1.2	13.1
1.3	12.8
1.4	12.6
1.5	12.5
1.6	12.3
1.7	12.2
1.8	12

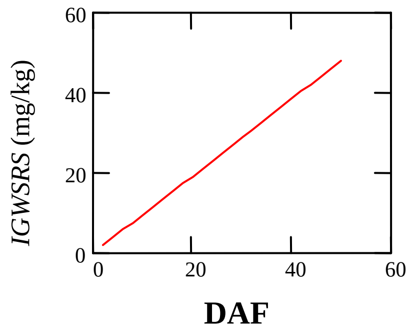
Sensitivity to ρ_b is small.



8. Sensitivity of remediation standard (*IGWSRS*) to Dilution Attenuation Factor (*DAF*). Results shown for xylene.

DAF	*IGWSRS* (mg/kg)
2	1.9
4	3.8
6	5.8
8	7.7
10	9.6
12	11.5
14	13.4
16	15.3
18	17.2
20	19.2
22	21.1
24	23
26	24.9
28	26.8
30	28.8
32	30.7
34	32.6
36	34.5
38	36.4
40	38.3
42	40.2
44	42.2
46	44
48	46
50	47.9

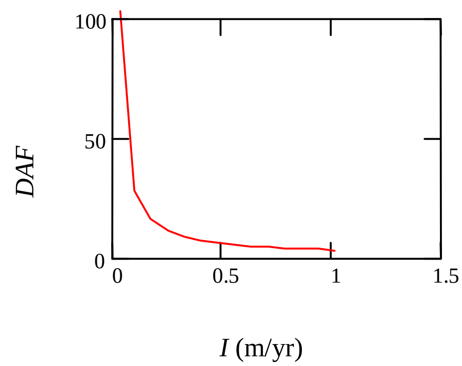
Sensitivity is linear with respect to *DAF*



9.   Sensitivity of Dilution Attenuation Factor (*DAF*) (and remediation standard (*IGWSRS*)) to infiltration rate (*I*). Results shown for xylene

I (m/yr)	*DAF*
0.025	127
0.102	33
0.178	19.8
0.254	14.5
0.33	11.6
0.406	9.8
0.483	8.5
0.559	7.6
0.635	6.9
0.711	6.4
0.787	5.9
0.864	5.6
0.94	5.3
1.016	5

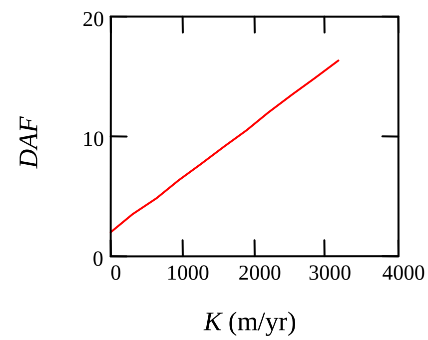
DAF (and cleanup) sensitivity is inversely proportional to infiltration rate, I. Mixing zone depth not constrained by aquifer thickness (4.2 m maximum).



10. Sensitivity of dilution attenuation factor (*DAF*) (and remediation standard (*IGWSRS*) to hydraulic conductivity (*K*). Results are shown for xylene.

DAF (and cleanup) sensitivity is slightly less than linear with respect to conductivity, K. Mixing zone depth not constrained by aquifer thickness in this calculation.

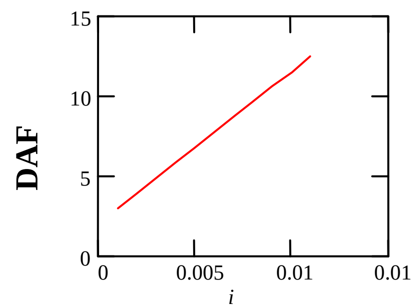
K (m/yr)	*DAF*
0.3	2
315	3.4
630	4.9
946	6.3
1261	7.7
1576	9.2
1891	10.6
2207	12
2522	13.4
2837	14.9
3152	16.3



11. Sensitivity of dilution attenuation factor (*DAF*) and remediation standard (*IGWSRS*) to gradient (i). Results are shown for xylene.

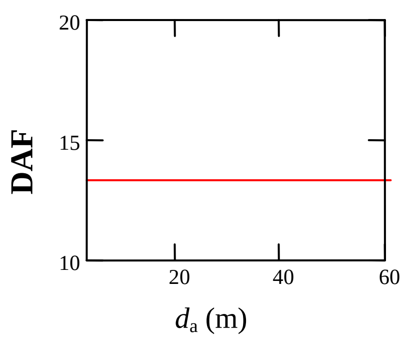
DAF (and cleanup standard) sensitivity is slightly less than linear with respect to gradient, i. Mixing zone depth not constrained by aquifer thickness in this calculation.

i	*DAF*
0.001	3
0.002	3.9
0.003	4.9
0.004	5.8
0.005	6.8
0.006	7.7
0.007	8.7
0.008	9.6
0.009	10.6
0.01	11.6
0.011	12.5



12. Sensitivity of dilution attenuation factor (*DAF*) (and remediation standard (*IGWSRS*)) to aquifer thickness (d_a). Results shown for xylene

Under default scenario, aquifer thickness has no affect on *DAF* or the remediation standard.



14. Effect of size of area of concern on the remediation standard. Results shown for xylene.

Remediation standard for xylene as a function of the size of the area of concern (mg/kg)			
	Length of Site Parallel to GW flow (m)		
	15.2	*30.5*	*152*
Aquifer thickness = 3.5 m	13	13	3
Aquifer thickness = 15.2 m	13	13	11

Under default conditions, a lower remediation standard results when the site length becomes large. However, this effect is reduced when the aquifer thickness increases.

References

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